APPENDIX AVAILABLE ON THE HEI WEBSITE

Research Report 199

Real-World Vehicle Emissions Characterization for the Shing Mun Tunnel in Hong Kong and Fort McHenry Tunnel in the United States

Xiaoliang Wang et al.

Appendix A. Additional Measurement and Modeling Information

This Appendix was reviewed solely for spelling, grammar, and cross-references to the main text. It has not been formatted or fully edited by HEI. This document was reviewed by the HEI Review Committee.

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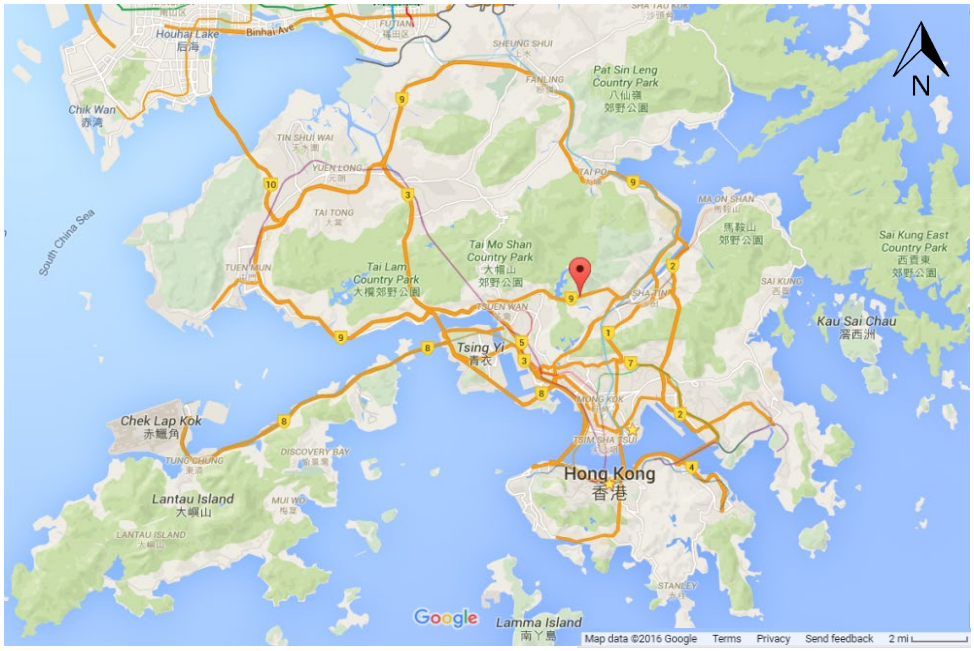
APPENDIX A. ADDITIONAL MEASUREMENT AND MODELING INFORMATION

Additional Field Measurement and Emission Calculation Information

(a)



(b)

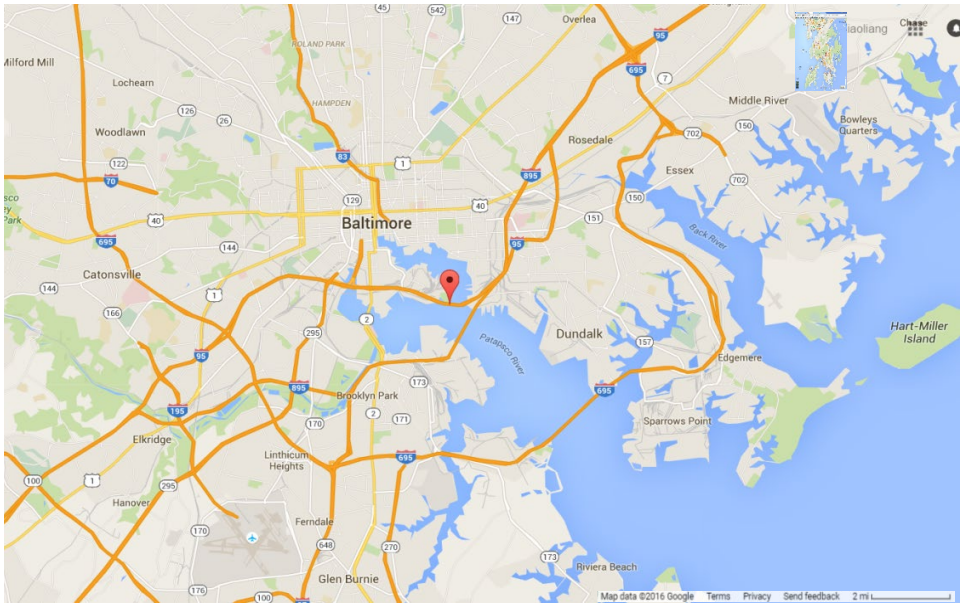


Figure A.1. Map locations of (a) Shing Mun Tunnel (SMT) in Hong Kong; and (b) Fort McHenry Tunnel (FMT) in Baltimore, MD, USA.

Table A.1. Instruments Used in the Shing Mun Tunnel (SMT) Study in Hong Kong

Make/Model	Equipment Type and Operating Principle	Measurement Range	Averaging Time
Gases			
Teledyne Model 300E (2 units)	CO analyzer by gas filter correlation infrared absorbance	0.04-1,000 ppm	1 min
Langan T15n (2 units)	CO by electrochemical sensor	0.1-200 ppm	1 s
Ionicon PTR-MS 500 (1 unit; Outlet 2/16–3/31/2015)	VOC by proton transfer reaction – mass spectrometry	1-512 amu; 1pptv-10 ppmv	1 s
Teledyne Model T200U (1 unit; Inlet)	$NO/NO_2/NO_x$ analyzer by chemiluminescence	50 ppt-2 ppm	1 min
Teledyne Model 200E (1 unit; Outlet 1/19/15-2/4/15 and 3/1/15-3/15/15)	$NO/NO_2/NO_x$ analyzer by chemiluminescence	0.4 ppb- 20 ppm	1 min
Thermo Model 42C (1 unit; Outlet 2/5/15-2/16/15)	$NO/NO_2/NO_x$ analyzer by chemiluminescence	0.4 ppb- 100 ppm	1 min
Teledyne Model T100U (2 units)	SO_2 analyzer by UV fluorescence	50 ppt- 20 ppm	1 min
PP Systems SBA5 (4 units)	CO_2 analyzer by non-dispersive infrared (NDIR)	15-5000 ppm	1.5 s
ATEC Model 8001 Automated Canister Sampler (2 units)	Canister sampler for C2 to C12 by laboratory analysis	NA	2 h integrated
ATEC Model 8000 Cartridge Sampler (2 units)	Carbonyl sampler for laboratory analysis	NA	2 h integrated
DRI Medium-volume Gas/ Particle Sampling System (2 units)	Quartz-fiber filter/XAD-4 volatile organic compounds sampler	NA	2 h integrated
Particles			
TSI DustTrak DRX (2 units)	Size segregated PM_1, $PM_{2.5}$, PM_4, PM_{10}, and PM_{15} by light scattering	0-150 mg/m^3	1 s
TSI CPC 3025A (2 units; 2/2–3/22/2015)	Particle number concentration by condensation growth and optical counting	0-10^5 #/cm^3 (≥~3 nm)	1 s
TSI CPC 3022 (Outlet)	Particle number concentration by condensation growth and optical counting	0-10^7 #/cm^3 (≥~7 nm)	1 s
AethLabs Model AE-52 (2 units)	Aethalometer for black carbon and UVPM by light attenuation	0.1-1000 µg/m^3	10 s
DRI 13-Channel Medium-volume Filter Sampling System (4 units)	Three channels are activated at each sampling period to collect filter samples for laboratory analysis	NA	2 h integrated
Meteorological			
Ambient Weather WS-2080 Weather Station (2 units)	Wind speed, wind direction, temperature, pressure, and relative humidity by anemometer and hygrometer	3–290 km/hr -40–65 °C 540–1100 hPa 0–100% RH	5 s
Traffic			
Video camera (3 units; Inlet, Outlet, and tunnel exit)	Traffic video	NA	NA

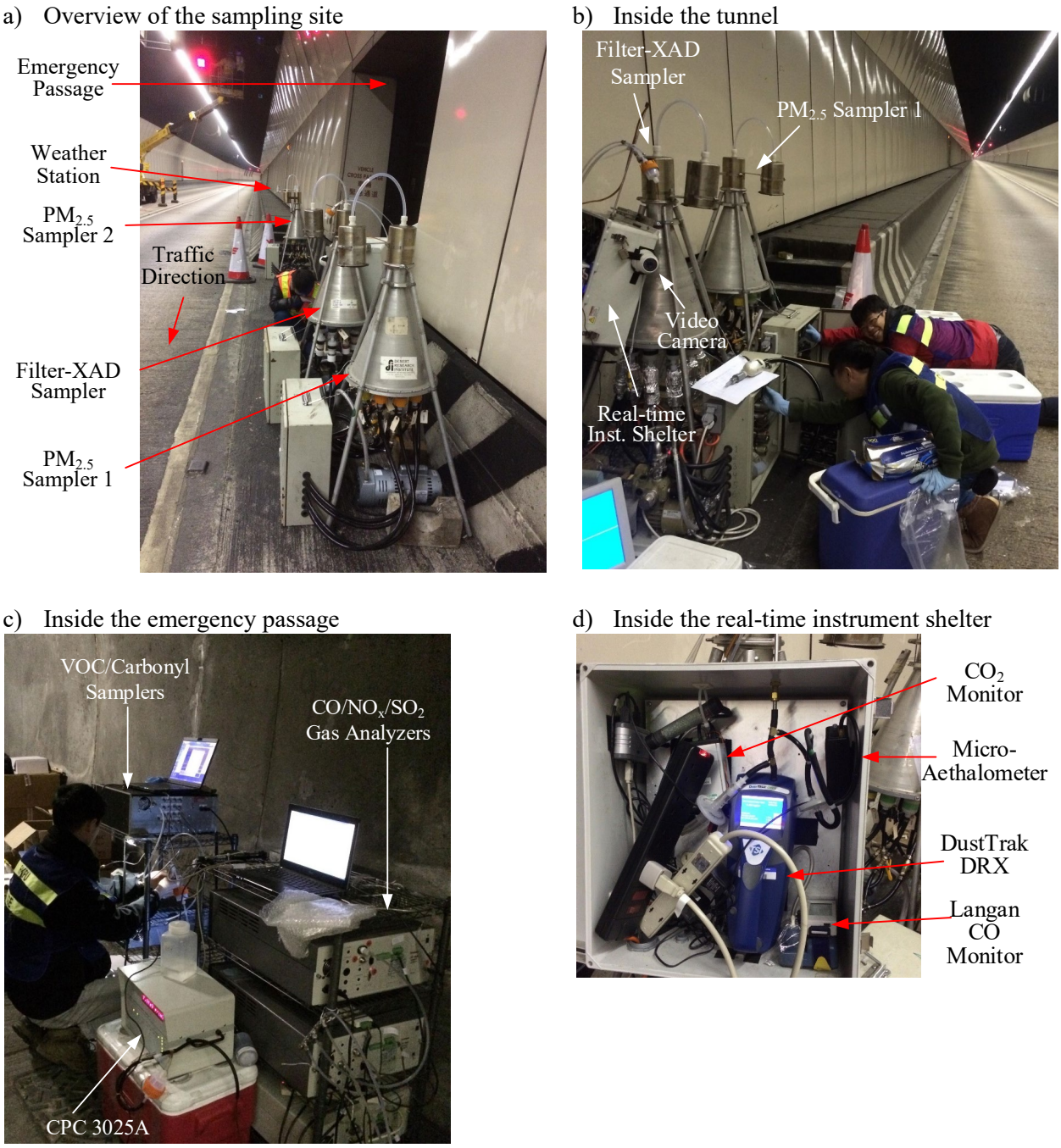


Figure A.2. Pictures of sampling setup at the outlet site in the SMT in Hong Kong during the 2015 study. $PM_{2.5}$ and Filter-XAD samplers were installed at the roadside of the tunnel, while continuous gas and particle instruments were both at roadside and inside the emergency passage.

Table A.2. Real-Time Measurement Periods and Number of Integrated Samples Collected in the 2015 Field Campaigns

Parameter	Sampling Period or Number of Sample Sets Collected		
	SMT (Winter/Spring)	FMT (Winter)	FMT (Summer)
Near real-time measurements:			
CO	1/19/2015 – 2/15/2015; 3/2/2015 – 3/31/2015	2/8/2015 – 2/15/2015	7/31/2015 – 8/6/2015
CO_2	1/19/2015 – 3/29/2015	2/8/2015 – 2/15/2015 (canister)	7/31/2015 – 8/6/2015
NO	1/19/2015 – 2/15/2015; 3/2/2015 – 3/24/2015	2/8/2015 – 2/15/2015	7/31/2015 – 8/6/2015
NO_x	1/19/2015 – 2/15/2015; 3/2/2015 – 3/24/2015	2/8/2015 – 2/15/2015	7/31/2015 – 8/6/2015
SO_2	1/19/2015 – 2/15/2015; 3/2/2015 – 3/31/2015	NA[a]	NA
VOCs	2/16/2015 – 3/31/2015	2/8/2015 – 2/15/2015	7/31/2015 – 8/62015
Black carbon	1/19/2015 – 2/15/2015; 3/2/2015 – 3/15/2015	None (instrument malfunction)	None (instrument malfunction)
Particle number concentration	1/19/2015 – 2/15/2015; 3/2/2015 – 3/18/2015	2/8/2015 – 2/15/2015 (from size distributions)	7/31/2015 – 8/6/2015 (from size distributions)
UFP size distribution	NA	2/8/2015 – 2/15/2015	7/31/2015 – 8/6/2015
$PM_{2.5}$	1/19/2015 – 3/31/2015	2/8/2015 – 2/15/2015	7/31/2015 – 8/6/2015
Wind speed and direction, temperature, pressure, and relative humidity	1/19/2015 – 3/31/2015	2/9/2015 – 2/15/2015 (T & RH only)	7/31/2015 – 8/7/2015 (T & RH only)
Traffic volume, speed, and class	1/19/2015 – 3/31/2015	2/9/2015 – 2/15/2015	7/31/2015 – 8/6/2015
Integrated measurements:			
NH_3	65	45	50
VOCs (C2-C12)	46	46	50
Carbonyls	59	46	50
Filter-XAD for PAHs	70	46	50
$PM_{2.5}$	63	45	50
Road dust for resuspension	6	NA	3

[a] Not applicable

Table A.3. Key Traffic and Tunnel Differences Between SMT and FMT

Parameters	SMT	FMT
Location	Hong Kong, China	Baltimore, U.S.
Sampling period	January-March 2015	February and July-August 2015
Traffic	53,000 vehicle/day; 13% LPG, 45% GV, and 42% DV	55,000 vehicle/day; >97% LD in Bore 3 and 8-45% HD in Bore 4
Vehicle condition	Hot stabilized; 80 km/hr	Hot stabilized; 89 km/hr
Average grade	+1.054%	-1.8% for the downhill section and +3.3% for the uphill section (ranging -3.76% to +3.76%)
Ventilation	Piston effect by vehicle movement	Air supplied from a duct beneath the roadway
Average temperature and RH	25 °C (16–32°C) and 53% (22–83%)	Winter: 7 °C (4–9°C) and 32% (16–61%) Summer: 30 °C (26–33°C) and 38% (26–65%)

Table A.4. Instruments Used in the Fort McHenry Tunnel (FMT) Study in Baltimore, MD

Model	Equipment Type/Operating Principle	Measurement Range	Averaging Time
Gases			
Monitor Labs 8830 or 9830	CO by continuous flow NDIR	0 - 200 ppm	10 s
TSI 8554 Q-TRAK	CO by electrochemical sensor, CO_2 by passive NDIR	0-500 ppm (CO). 0-5000 ppm (CO_2)	1 min
PP Systems SBA5	CO_2 analyzer by non-dispersive infrared (NDIR)	15-5000 ppm	1.5 s
Horiba APNA-360CE or TEI 42	NO, NO_2 by continuous flow chemiluminescent	0 - 1000 ppb	10 s
2BTech 400+401	NO, NO_x by continuous flow photometric	0 - 2000 ppb	10 s
DRI canister sampler	Speciated VOC by canister	N/A	≥ 10 s
DRI carbonyl sampler	Speciated aldehydes by DNPH cartridge	N/A	≥ 0.5 h
Particles			
TSI SMPS 3936	Particle 7–300 nm size distribution in 100 bins by electrical mobility classification	0-10^7 particles/cm^3	135 s
DRI filter sampler	$PM_{2.5}$ filter sample collection	0-1 mg/m^3	≥ 1 h
DRI fine particle/SVOC sampler	TIGF filter and XAD-4 adsorbent	N/A	≥ 1 h
Meteorological			
HOBO U10	Temperature by Passive Transducer	-20 to 70 °C	10 min
HOBO U10	Relative humidity by passive transducer	25-95%	10 min
Traffic			
Miovision Scout VCU	Traffic and vehicle information	N/A	5 min

Table A.5. Fleet Average Fuel Economy of Major Vehicle Categories Assumed in the FMT Distance-Based Emission Factor Calculation (*www.afdc.energy.gov/data/*)

	Motorcycle	Light-Duty Vehicle	Light Truck	Buses	Delivery Truck	Class 8 Truck
Gasoline (mile/gallon)	43.54	21.64	17.16	4.03	6.64	5.29
Diesel (mile/gallon)	48.17	23.93	18.98	4.46	7.35	5.85

a) View from the louvered wall toward ventilation fans that supply air into the lower ventilation ducts of the tunnel.

b) View toward the louvered wall of the east ventilation building.

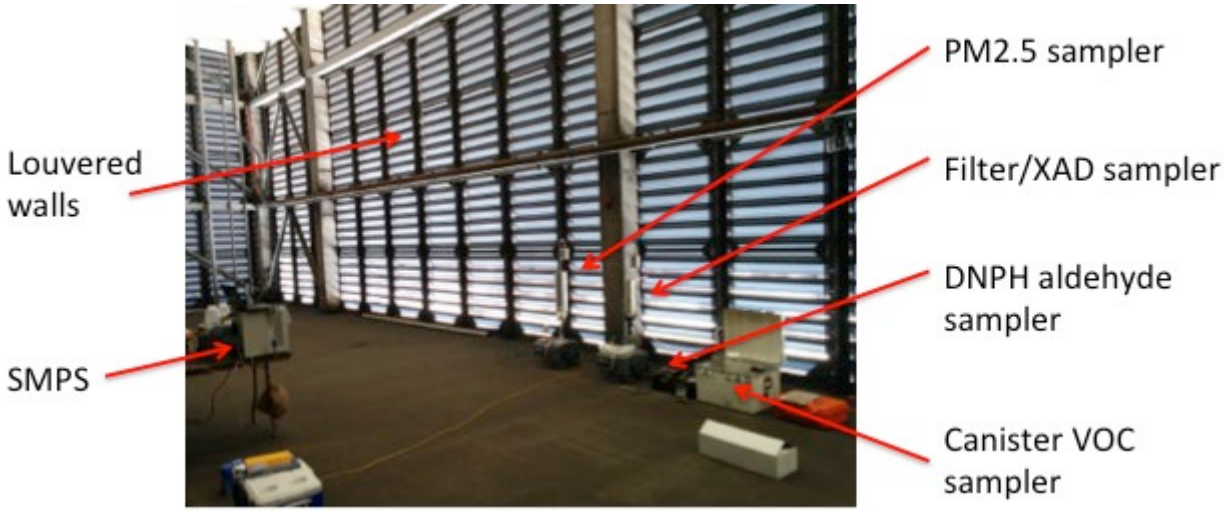
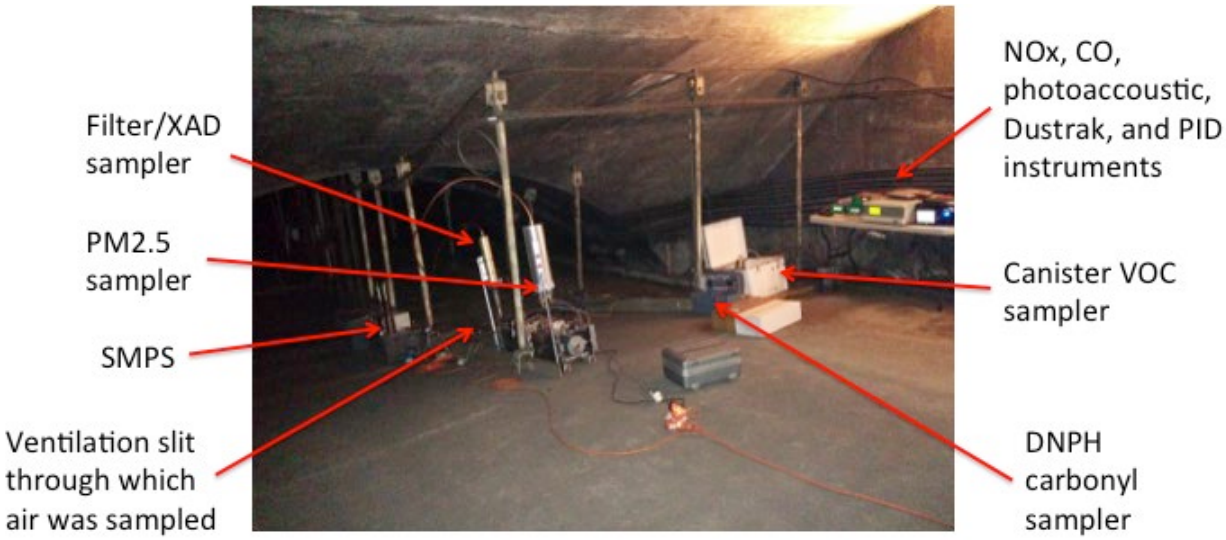


Figure A.3. Sampling Setup in the East Ventilation Building of FMT During the 2015 Study.

a) Sampling setup in Bore 4 of FMT.



b) Sampling setup in Bore 3 of FMT.

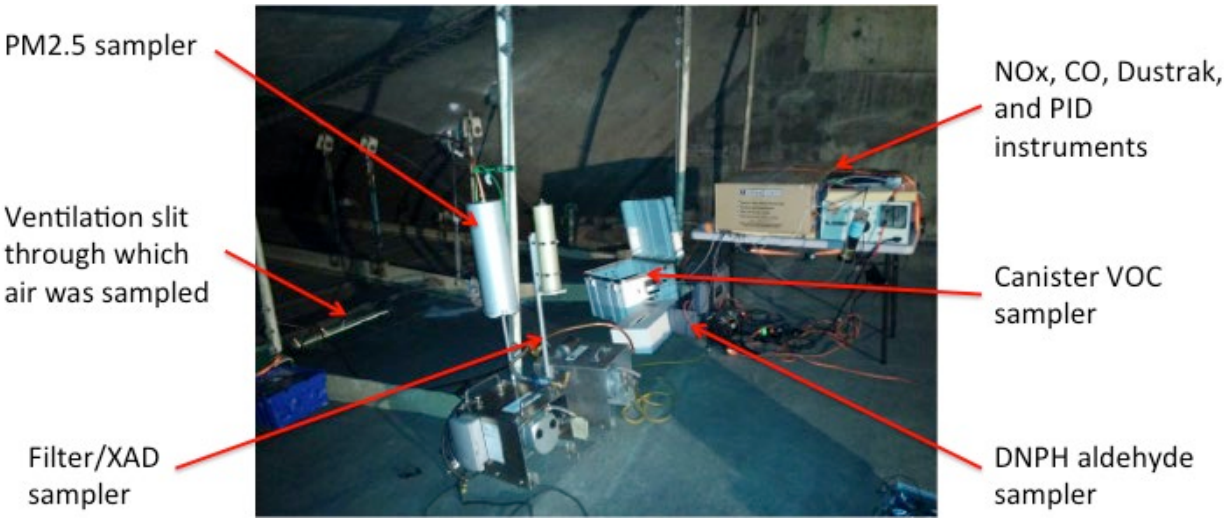


Figure A.4. Sampling Setup in Bores 3 and 4 of FMT in Baltimore, MD, USA, During the 2015 Study.

Additional EMFAC-HK Modeling Information

Table A.6. The 16 EMFAC-HK Vehicle Classes and Corresponding Vehicle Classifications from Manual Traffic Counting for the SMT Monitoring Periods in 2003 and 2015

EMFAC-HK Vehicle Class	Description	EMFAC-HK Code	Traffic Counting Vehicle Class 2003	Traffic Counting Vehicle Class 2015
1	Private cars	PC	Private car	Private car
2	Taxi	TAXI	Taxi	Taxi
3	Light goods vehicles (<=2.5t)	LGV3	LGV[a]	LGV[a]
4	Light goods vehicles (2.5-3.5t)	LGV4	LGV[a]	LGV[a]
5	Light goods vehicles (3.5-5.5t)	LGV6	LGV[a]	LGV[a]
6	Medium & heavy goods vehicles (5.5-15t)	HGV7	HGV[b]	MGV
7	Medium & heavy goods vehicles (>=15t)	HGV8	HGV[b]	HGV
8	Public light buses	PLB	Light buses[c]	Light buses[c]
9	Private light buses (<=3.5t)	PV4	Light buses[c]	Light buses[c]
10	Private light buses (>3.5t)	PV5	Light buses[c]	Light buses[c]
11	Non-franchised buses (<6.4t)	NFB6	Big bus[d]	Single-deck bus[e]
12	Non-franchised buses (6.4-15t)	NFB7	Big bus[d]	Single-deck bus[e]
13	Non-franchised buses (>15t)	NFB8	Big bus[d]	Single-deck bus[e]
14	Single-deck franchised buses	FBSD	Big bus[d]	Single-deck bus[e]
15	Double-deck franchised buses	FBDD	Big bus[d]	Double-deck bus
16	Motor cycles	MC	Motorcycle	Motorcycle

[a] Apportioned from LGV counts to LGV3, LGV4, and LGV6 based on VKT ratio in EMFAC-HK (Table A.7).

[b] Apportioned from HGV counts in 2003 to HGV7 and HGV8 based on the counted HGV/MGV ratio in 2015

[c] Apportioned from light bus to PLB, PV4, and PV5 counts based on VKT ratio in EMFAC-HK (Table A.7).

[d] The big bus count in 2003 was first apportioned to FBDD and single-deck bus based on the counted ratio in 2015, and the single-deck bus count was then apportioned to NFB6, NFB7, NFB8, and FBSD based on VKT ratio in EMFAC-HK (Table A.7).

[e] Apportioned from single-deck bus counts to NFB6, NFB7, NFB8, and FBSD based on VKT ratio in EMFAC-HK (Table A.7).

Table A.7. EMFAC-HK Default Breakdown of Registered Vehicle Number and VKT by Vehicle Classes in 2003 and 2015

Vehicle Class	Percentage of Registered Vehicle Number		Percentage of Fleet VKT	
	2003	2015	2003	2015
PC	66.6%	71.9%	32.6%	39.9%
TAXI	3.3%	2.5%	23.9%	21.4%
LGV3	0.3%	0.1%	0.3%	0.1%
LGV4	6.9%	7.0%	8.0%	9.8%
LGV6	5.4%	2.9%	8.5%	5.4%
HGV7	1.9%	1.6%	2.9%	2.9%
HGV8	6.3%	4.2%	9.7%	7.7%
PLB	0.9%	0.6%	4.1%	3.4%
PV4	0.2%	0.1%	0.2%	0.2%
PV5	0.2%	0.5%	0.3%	0.8%
NFB6	0.6%	0.4%	1.2%	0.9%
NFB7	0.6%	0.3%	1.2%	0.6%
NFB8	0.2%	0.5%	0.4%	1.0%
FBSD	0.1%	0.1%	0.3%	0.2%
FBDD	1.2%	0.8%	4.6%	3.5%
MC	5.5%	6.7%	1.8%	2.3%
All Fleet	100.0%	100.0%	100.0%	100.0%

Table A.8. EMFAC-HK Default Breakdown of (a) Registered Vehicle Number and (b) VKT By Fuel for Each Vehicle Class in 2003 and 2015.

(a)

Vehicle Class	Percentage of Registered Vehicle Number by Fuel for Each Vehicle Class							
	2003				2015			
	NCAT[a]	CAT[a]	Diesel	LPG	NCAT[a]	CAT[a]	Diesel	LPG
MC	100%	0	0	0	46.34%	53.66%	0	0
PC	4.42%	94.94%	0.65%	0	0.38%	98.61%	1.02%	0
TAXI	0	0	0.30%	99.70%	0	0	0	100%
LGV3	27.59%	37.93%	34.48%	0	0	14.29%	85.71%	0
LGV4	0.73%	5.52%	93.75%	0	0	3.43%	96.57%	0
LGV6	0	0	100%	0	0	0	100%	0
HGV7	0	0	100%	0	0	0	100%	0
HGV8	0	0	100%	0	0	0	100%	0
PLB	0	0	92.94%	7.06%	0	0	30.00%	70.00%
PV4	0	0	100%	0	0	100%	0	0
PV5	0	0	95.24%	4.76%	0	0	70.00%	30.00%
NFB6	0	0	100%	0	0	0	100%	0
NFB7	0	0	100%	0	0	0	100%	0
NFB8	0	0	100%	0	0	0	100%	0
FBSD	0	0	100%	0	0	0	100%	0
FBDD	0	0	100%	0	0	0	100%	0

(b)

Vehicle Class	Percentage of VKT by Fuel for Each Vehicle Class							
	2003				2015			
	NCAT	CAT	Diesel	LPG	NCAT	CAT	Diesel	LPG
MC	100%	0	0	0	32.48%	67.52%	0	0
PC	3.31%	96.17%	0.52%	0	0.25%	98.52%	1.23%	0
TAXI	0	0	0.17%	99.83%	0	0.05%	0	99.95%
LGV3	24.14%	37.93%	37.93%	0	0	10.00%	90.00%	0
LGV4	0.63%	6.13%	93.25%	0	0	3.26%	96.74%	0
LGV6	0	0	100%	0	0	0	100%	0
HGV7	0	0	100%	0	0	0	100%	0
HGV8	0	0	100%	0	0	0	100%	0
PLB	0	0	92.89%	7.11%	0	0	30.65%	69.35%
PV4	0	0	100%	0	0	100%	0	0
PV5	0	0	92.00%	8.00%	0	0	72.50%	27.50%
NFB6	0	0	100%	0	0	0	100%	0
NFB7	0	0	100%	0	0	0	100%	0
NFB8	0	0	100%	0	0	0	100%	0
FBSD	0	0	100%	0	0	0	100%	0
FBDD	0	0	100%	0	0	0	100%	0

[a] NCAT: gasoline vehicles without a catalytic converter; CAT: gasoline vehicles equipped with a catalytic converter

Additional MOVES Modeling Information

The direct measurement of emission factors for a large fleet of on-road vehicles during this project provides an opportunity to test the effectiveness of the current MOVES2014a in estimating the cumulative on-road emissions from a specific road segment. The MOVES model was designed for use in State Implementation Plans and Transportation Conformity Analyses to "provide an accurate estimate of emissions from cars, trucks and non-highway mobile sources under a wide range of user-defined conditions" (U.S. EPA 2015). It calculates the emissions of a wide range of pollutants, including mobile source air toxics, criteria gases, and particulate matter, for up to 13 vehicle categories each broken down by fuel type and model year. Emissions are also delineated by the specific activity and/or process creating them, e.g., running vs. start exhaust, evaporative fuel leaks, brake and tire wear. Users may specify the location, roadway type(s) and time period (month, year, time of day), allowing the program to determine appropriate weather and traffic patterns for the estimates or input detailed information on the meteorological conditions, roadway length and grade, and vehicle speeds if a more tailored output is desired.

For this project MOVES was run in Project mode with "Zone and Link" geographic bounds to specify actual driving and meteorological conditions (temperature and RH) observed in the tunnel during in-situ emissions measurements. Second-by-second vehicle speed logs were recorded while driving thru tunnel, keeping pace with traffic, using a DavisNet CarChip Pro device connected to the vehicle's OBD-II system. Multiple drive-throughs were recorded for both bores and alternate lanes in each bore, when possible, on weekdays and weekends and various times of day. The exact time when the vehicle entered and exited the tunnel was recorded for each drive-throughs as well as the time when the vehicle stopped at the exit toll plaza. For each second of the drive-through speed traces the vehicle specific power (VSP) was calculated (Jiménez-Palacios 1998) but neglecting the term for aerodynamic drag (since the normal estimate of drag is probably not accurate for vehicles inside a tunnel due to the piston effect). The mean VSP for each drive-through was calculated, as shown in Figure A.5, and Link Drive Schedules were created from traces with high and low VSP to represent the range of driving conditions in the tunnel. A single link (roadway segment), comprised of the second-by-second vehicle speed and roadway grade (Pierson et al. 1996), was input for each MOVES run. Since traffic conditions varied during measurement periods and there were only a limited number of drive-through traces, the average of the high-VSP and low-VSP runs was used to represent emissions for each season and the range, (high-low)/2, as the uncertainty. The observed VSP were only used to select representative driving cycles; no adjustments to the MOVES VSP calculation were made.

For vehicle selection, heavy-duty gasoline vehicles and school buses were excluded since few were expected on an interstate toll highway. Also excluded were short-haul trucks, motorhomes, and refuse trucks since MOVES emission factors were zero for all species of interest in initial runs, and all fuels other than diesel, gas, and ethanol since the number of vehicles using these is unknown but expected to be small. Default vehicle population data from MOVES does not list any electric, compressed natural gas (CNG), or LPG powered vehicles other than CNG transit buses, which are not used by Maryland Department of Transportation (MDOT). The presence of approximately 40% hybrid diesel/electric buses in the Maryland Transportation Authority (MDTA) transit fleet was slightly problematic since we have no accurate way to divide up the buses, which account for 1–2% of vehicles in Bore 4, and MOVES does not predict emissions for hybrid engines. Only emissions from running exhaust, crankcase running exhaust, evaporative permeation, evaporative fuel leaks, and brake and tire wear processes were calculated, since no engine starting or refueling and minimal idling occurs in the tunnel. "Evaporative fuel vapor venting" was also excluded since this is not allowed unless all hours of the day are modeled.

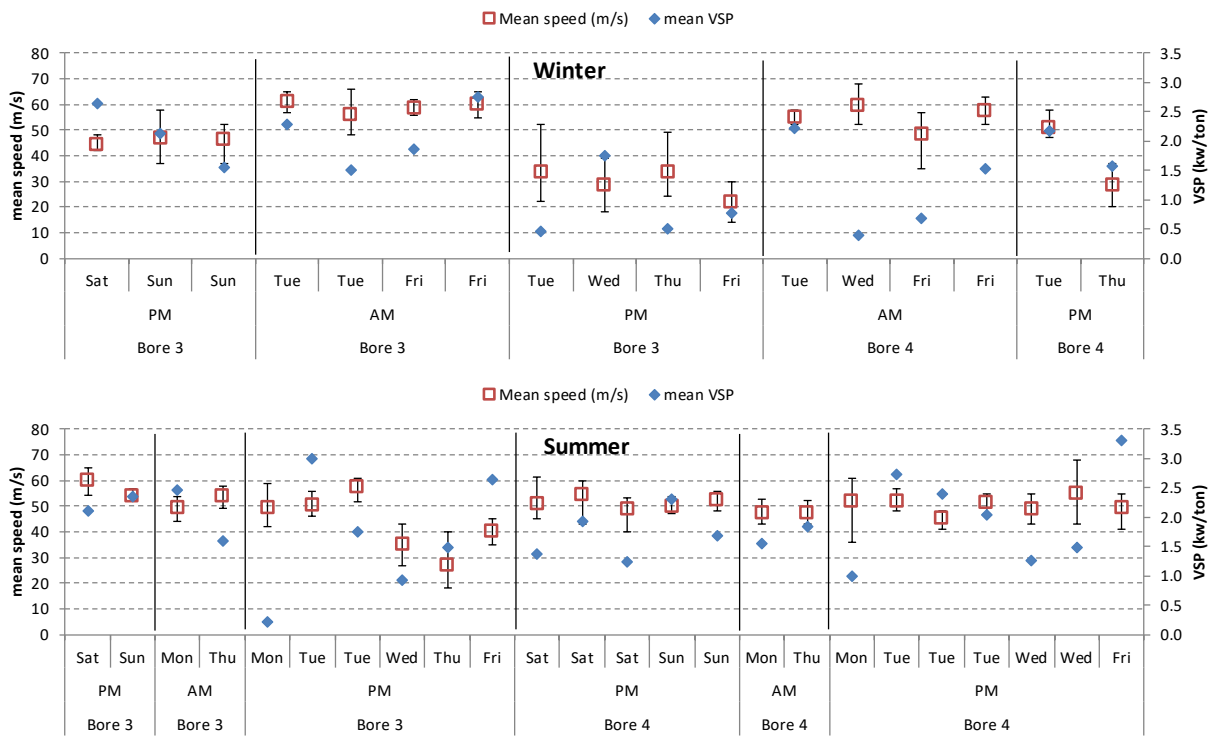


Figure A.5. Average speed and VSP of traffic in tunnel during drive-throughs in the 2015 FMT study. Error bars indicate the range (10% to 90%) of second-by-second vehicle speed recorded.

In post-processing, in order to convert the MOVES output in g/km for each vehicle/model year/process/fuel combination to fleet emissions for each measurement period, the "rateperdistance" table was multiplied by the corresponding vehicle counts determined from video surveillance. The vehicle counts table was created as follows:

1) To account for differences between MOVES and video source categories, the following conversions were used:

<u>Miovision → MOVES</u>
Motorcycles = Motorcycle (gas)
Cars = Passenger Car (gas, diesel, E85) + Passenger Truck (gas, diesel, E85)
Light Goods Vehicles = Light Commercial Trucks (gas, diesel, E85)
Buses = Transit Bus (diesel) + Intercity Bus (diesel)
Single-Unit Trucks = Single Unit Long-Haul Truck (diesel)
Articulated Trucks = Combination Long-haul Truck (diesel)

Since the video processing did not distinguish between Passenger Cars and Passenger Trucks, the fraction of total passenger vehicles that were trucks (including SUVs and vans) was calculated from default MOVES "sourcetypeyear" table that lists population of vehicles by source type and age (data are based on national registration records and interpolation until 2011, after which they are projection). For example**:**

- *F_{PT} = (population of Passenger Trucks 2015 fleet)*(population of Passenger Trucks /[Passenger Cars + Passenger Trucks]) = adjusted fraction of Passenger Trucks in fleet*
- *$N_{PT} = N_{cars}*F_{PT}$, $N_{PC} = N_{cars}*(1-F_{PT})$, where N_{cars} is the number of cars per hour reported by the video surveillance for a particular sampling period.*

For transit and intercity buses, the observed counts were split equally since national data from 1999–2010 indicated 40%-45% transit (EPA's data for 2011, taken from federal registration records, indicates about 70% of non-school buses as Transit, but this is anomalous in comparison to all prior years and no more recent data is reported), but a somewhat higher fraction is expected in a major urban area like Baltimore.

2) Next, the number of vehicles of each type was apportioned by age distribution and diesel, gas, and E85 fuel fractions using VMT data in the "movesactivityoutput" table generated from a national scale run of the model.[1] Since 2014 emissions input data for Baltimore County, provided by EPA, indicated that only about 1.8% of E85-capable vehicles actually used that fuel, 98.2% of all E85 fueled vehicles were reapportioned to gasoline use. This may still be an overestimate for the Baltimore area since ethanol fuel is more prevalent in the central states and California but represents too small a fraction of total emissions to significantly affect fleet emission factors.
3) The adjusted fleet data was multiplied by the emission rate of each pollutant to yield emissions (g/km) by emission process, vehicle type, fuel, and model year.
4) Finally, the emissions for each pollutant were summed over all emission process, vehicle types, fuels, and model years to give the emission rates for the combined fleet in g/km for each measurement period.

All emission factors were zero for the following pollutants: Acenaphthene particle, Dibenzo(a,h)anthracene gas, Indeno(1,2,3,c,d)pyrene gas, MTBE, H_2O (aerosol). NMOG, NMHC, VOC, and NO_x from Crankcase Exhaust were zero for some HD trucks and buses (however, it was only a small fraction of running exhaust for other vehicle types). As noted above, short-haul trucks, motorhomes, and refuse trucks emission rates were zero for all species of interest.

For comparison with measurements, the MOVES output emission factors were converted to fuel-carbon based units (g/kg-C) by dividing the pollutant specific distance-based EF_D by $12 \times (EF_D\_CO_2/44 + EF_D\_CO/28)/1000$, where $EF_D\_CO_2$ and EF_D_CO are the distance-based emission factors for CO_2 and CO, respectively. In order to reduce the possible effect of unaccounted-for outliers such as gross high-emitters or unexpected vehicle type/fuel combinations, rather than compare results for individual measurements, the measurements were divided into three categories based on the relative fraction of heavy-duty vehicles observed (see Figure A.6): LD ≥ 97% (Bore 3 daytime runs), 8–15% HD vehicles (Bore 3 overnight and Bore 4 weekends and afternoons), and 30–45% HD vehicles (Bore 4 weekday mornings).

[1] The "movesactivityoutput" table contains estimates of VMT for the location (county and roadway type) and time (year, month, day-of-week, hours) chosen in the run specification. These estimates are broken down by source category (vehicle type), model year, and fuel type. The methodology used for these estimates is described in "Population and Activity of On-road Vehicles in MOVES2014 Draft Report" EPA-420-D-15-001, July 2015. We are not able to evaluate how accurately this distribution estimate represents the actual fleet since no recent vehicle registration data for vehicles using the FMT is available.

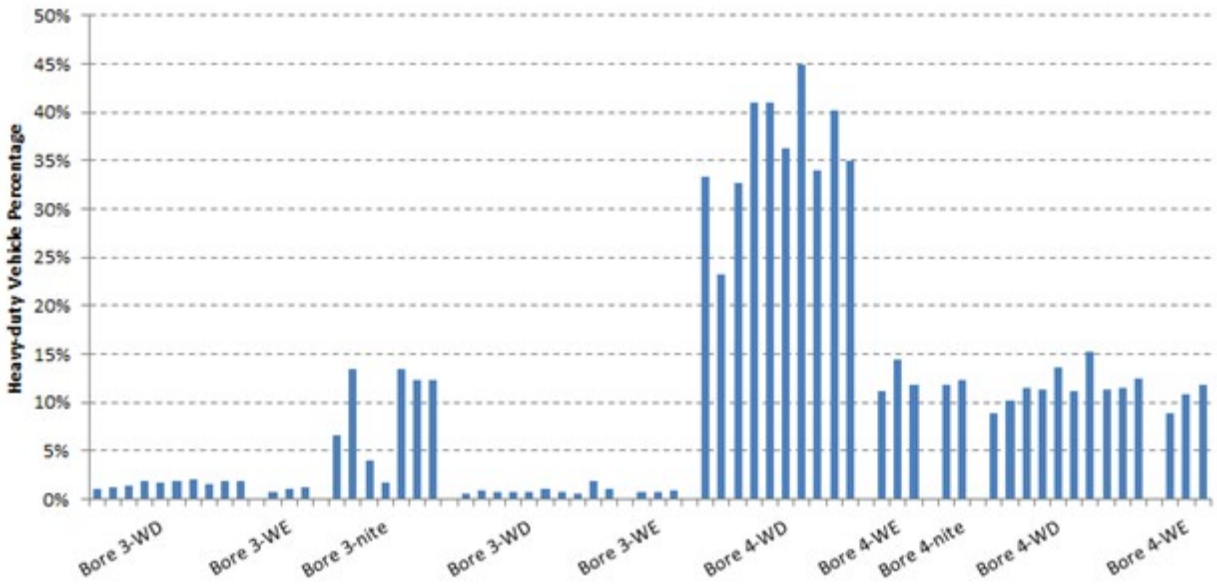


Figure A.6. Percentage of heavy-duty vehicles counted during all in-tunnel FMT measurement periods in 2015 grouped by bore, weekday or weekend, and time of day.

Additional Source Apportionment Information

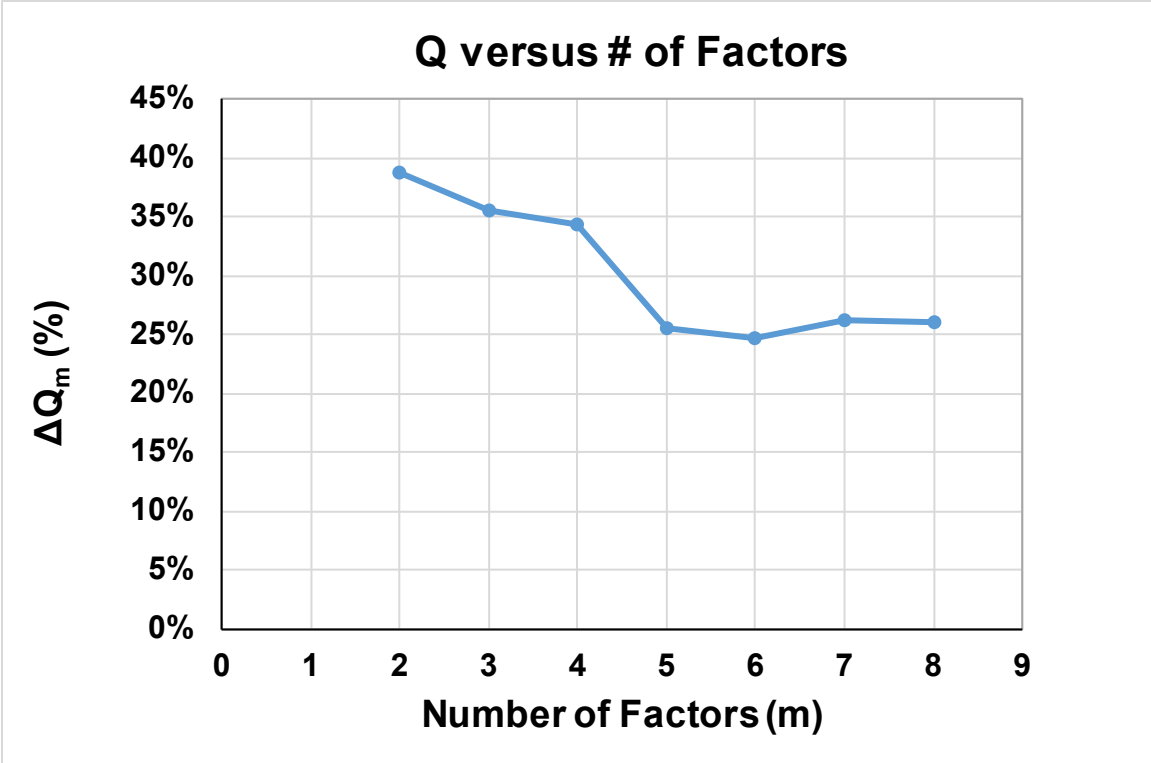


Figure A.7. Fraction of Q value change as number of factors increases from m to m + 1 in the PMF modeling for SMT. Q value change stabilizes after m = 5.

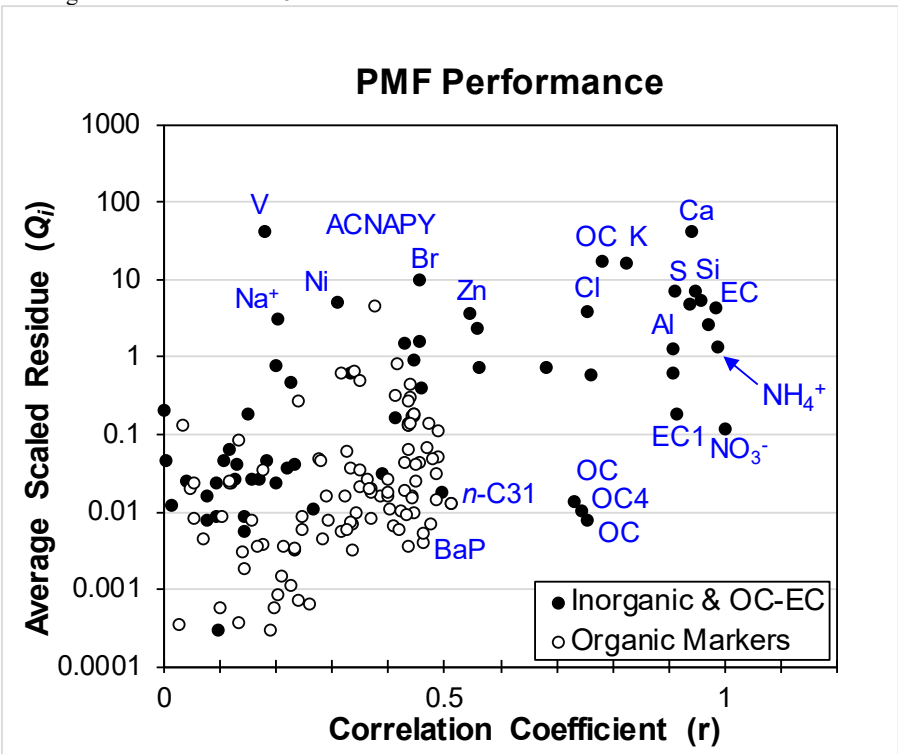


Figure A.8. PMF fitting performance by $PM_{2.5}$ species in the SMT, as indicated by the correlation between measured and modeled concentrations and average scaled residuals ($Q_i = \Sigma_t q_{i,t}^2/N$). Key $PM_{2.5}$ species are labeled.

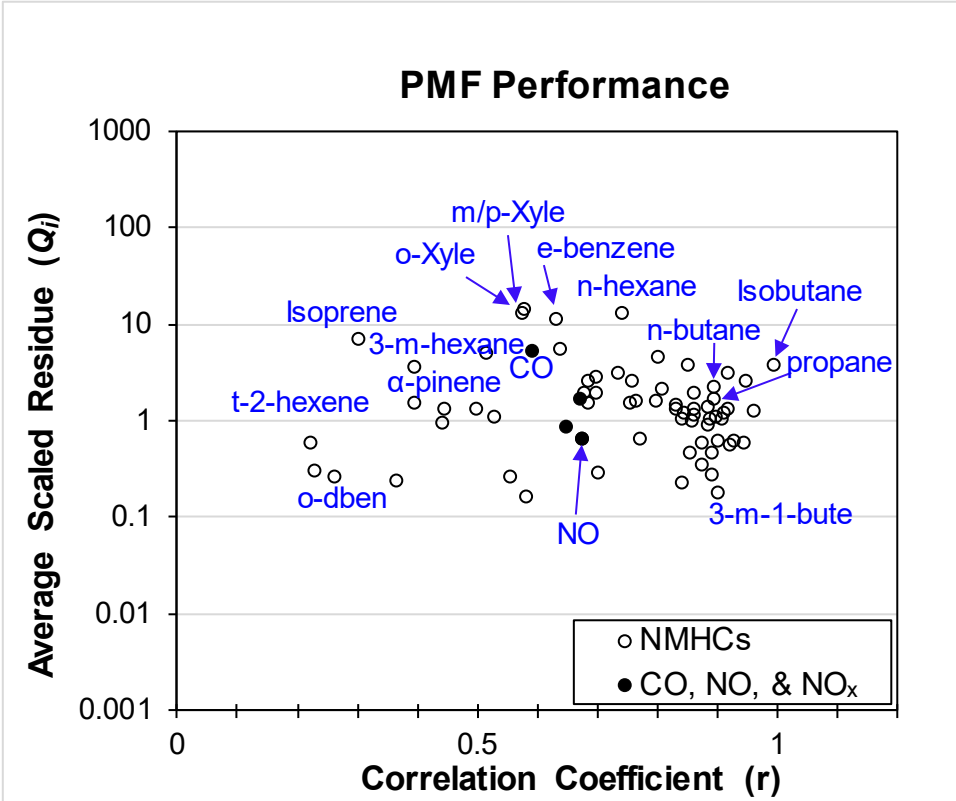
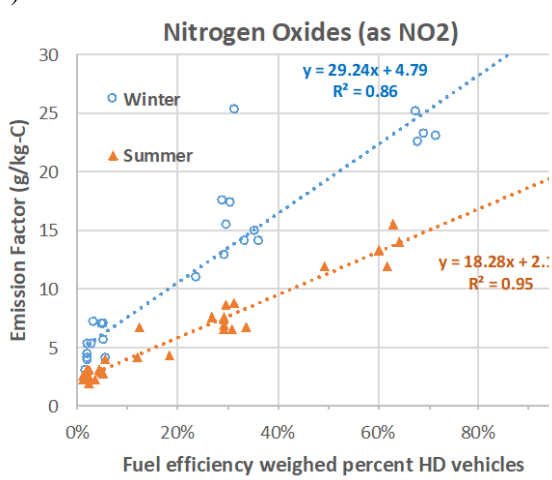
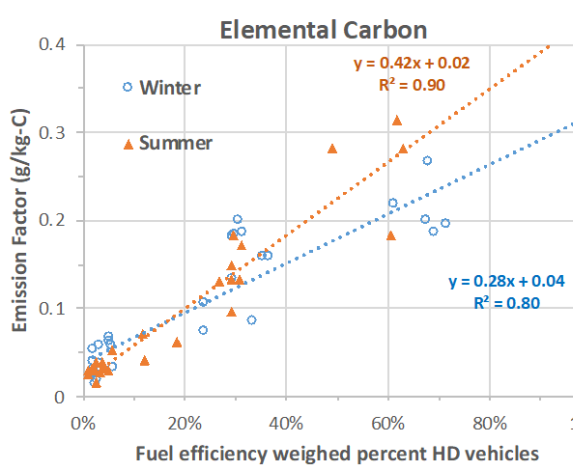


Figure A.9. PMF fitting performance by gas species in the SMT, as indicated by the correlation between measured and modeled NMHC concentrations and average scaled residuals ($Q_i = \Sigma_t q_{i,t}^2/N$). Key NMHC species are labeled.

a)



b)



c)

d)

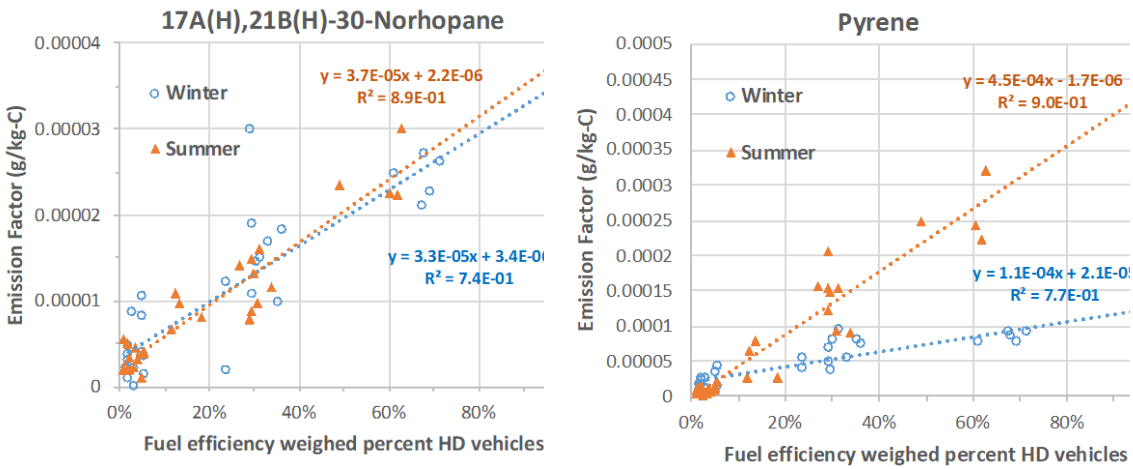


Figure A.10. Examples of linear regression method used to determine light-duty vehicle (intercept) and heavy-duty vehicle (slope + intercept) emission factors from FMT samples in 2015. The HD percent was estimated as the total number of buses, single-unit and articulated trucks divided by the total number of vehicles logged by the traffic video analysis during each sampling period.